Characteristics of the Severe Rollover Crashes in the UAE Using In-Depth Crash Investigation Data

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***Abstract*—**Rollover crashes are complex events entailing interactions of driver, road, vehicle, and environmental factors. The primary objective of this paper is to present an empirical approach that can be used to characterise the rollover crashes and to identify some of the important factors that may lead to rollovers. Among the studied factors are the vehicle types and the rollover occurrence rate after hitting various barrier types. The carried analysis indicated that 71% of the rollover crashes occurred after impact and the type of rollover initiation is “trip/turn over” (nearly 50%). It was also found that light trucks (LTVs) vehicles are more likely to rollover than the sedan vehicles. Barrier impacts are associated with increased incidence of rollover.

***Keywords*—**Empirical, hitting barrier, in-depth crash investigation, rollover, severe crash.

I. Introduction

ROLLOVER crashes are complex events with the interaction of driver, road, vehicle, and environmental factors. According to some recent United Arab Emirates (UAE) data, around one in every five fatalities results from a rollover crash [1], which is similar to Australia [2]. In the USA, the proportion is even higher; around one in three fatalities in a vehicle crash involving a rollover [3]. In comparison, fewer fatality rates are due to rollover crashes in European countries; one in five to ten fatalities in the UK [4], [5].

Rollover crashes are particularly categorized into two groups; tripped (95% of single-vehicle rollovers are tripped) or un-tripped [6]. A tripped rollover occurs due to tripping from external (vertical or lateral) inputs, such as exiting the roadway with sliding in roadside, grasping the tires into soil (sand, mud), or hitting object (curb, guardrail, small trees etc.). On the other hand, an un-tripped rollover happens due to high lateral acceleration from a sharp turn (i.e. the result of steering input, speed, and friction with the ground during high-speed collision avoidance manoeuvres) and not due to external tripping [7]. NHTSA data indicate that about 95% of rollovers in single-vehicle crashes were tripped, while the un-tripped rollovers occur less than 5% of the time [8].

Rollover crashes are related to the vehicle's stability. The stability is measured by the Static Stability Factor (SSF) of the vehicle, which is the ratio of one half its track width to its Centre of Gravity (CG) height [9]. In general, a high CG with a narrow track width can make the vehicle unstable in fast turns or sharp changes of direction. The problem is most pronounced in LTVs, which have a higher ground clearance for off-road driving. The term LTVs is used herein to refer to vans, sport utility vehicles (SUVs), and pickup trucks under 4,536 kilograms (10,000 pounds) gross vehicle weight. The term is also used by NHTSA in referring to the same vehicles. Studies have indicated that the percentage of four-wheel-drive (4WD)/SUV involved in these crashes is higher than the percentage of these vehicle types in the population of vehicles. Kweon and Kockelman [10], in their study of the overall injury risk to different drivers, highlighted the negative correlation between rollover risk and SSF. They reported an average SSF value of 1.400 for passenger cars, 1.153 for vans, and 1.087 for SUVs.

Keall and Newstead [11], in their assessment of whether SUVs are dangerous vehicles, indicated that due lower SSF values, SUVs have higher risk of rollover. The proportion of fatal crashes which involved a rollover differs by vehicle type. According to the NHTSA [12], the percentages of rollover-related fatal injuries are 15.3% for passenger cars, 26.3% for pickups, 31.4% for utility vehicles, 16.7% for vans, and 13.6% for large trucks. Rollovers do not only constitute a higher proportion of crashes in which SUVs are involved, but also they result in a significantly worse outcome for SUV occupants than for other passenger vehicle occupants [11]. Utility vehicles (commonly referred to as SUVs) experienced the highest rollover rate (31.4%) in fatal crashes [3].

Roadside barriers are designed to deflect deviant vehicles back onto the roadway. However, there are concerns that LTVs (their greater mass and height ones) may not be well catered with barriers. This concern was verified on LTVs through an impact test using a 1500-kg impact force, 70 mph (112 kph) speed, at an angle of collision of 70° [13]. LTVs were approximately three times more prone to overturn than passenger cars in police-reported guardrail (barrier) crashes considering the analysis of FARS and GES during 2000-2005 [14]. FARS and GES are providing a limited description of the barrier type mainly depended on police-reported crashes [15].

Rollover crashes generate a number of serious injuries, as well as fatalities. Previous biomechanical studies have identified information pertaining to the nature and mechanisms of the head, face, and neck injuries [16]-[22], spine injury [23]-[25], cervical spine injury [26], [27], thoracic spine injury [26]; chest (thoracic) injury [28]. Additionally, in epidemiological studies several factors for serious (AIS 3+)

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and fatal injuries have been identified. These factors included occupant ejection [4], [29]-[32], lack of seatbelt use [4], [29], [33]-[39], number of quarter turns [18], [29], [34], [35], [37], [38], occupant's seating position [16], [34], [35], [40], [41], roof crush [16], [24], [30], [40], [42]-[44], vehicle type [25], [29], [36], [38], [39], hitting objects [39], median cross-section design characteristics [33], occupant age, gender, and alcohol consumption [36], [39].

In conclusion, rollover crashes represent a significant portion of the accidents worldwide. Initial assessment of data in the UAE indicated that such crashes contribute to almost 20% of fatalities due to RTAs [1]. Studying the environmental factors that may contribute to these rollovers can help in defining the measures to reduce such crashes. A particular factor of interest herein is the relationship between the rollovers and the roadside barriers. Here, we attempt to address the research question on whether there are specific characteristics of such crashes in terms of initiation, location and vehicle types, and whether there is a relationship between the rate of rollover occurrence and the roadside barriers.

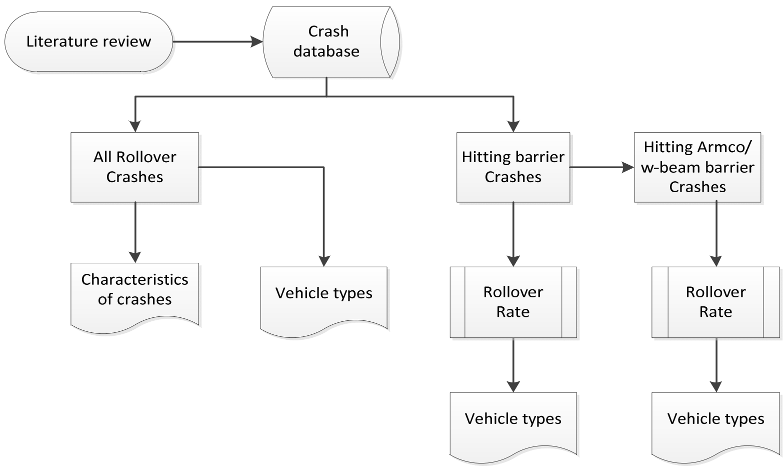

Fig. 1 Framework of the study analysis

II. Analysis Procedure

In order to investigate the crash occurrences of vehicles with rollover more closely, analysis crash data are conducted to determine the nature of real world rollover crashes. The objectives of this paper are:

1) Analyse the features of rollover crashes;
2) Demonstrate the rollover crashes rate considering the contribution of vehicle types; and
3) Associate the rollover occurrence rate with the hitting barrier crashes.

This research is achieved through three main steps. In the first step, all rollover crash data are used to determine whether differences exist between the likelihood of rollover by vehicle types and describe the characteristics of rollover crashes. Then, the rollover occurrence rate (after hitting the barrier) is studied, and differences between the likelihood of rollover by vehicle types are examined.

The framework of the conducted analysis is shown in Fig. 1 below and it entails the three stages (branches) of the research: one is selected to assessing all rollover crashes, one is the comprehensive evaluation of rollover crashes after hitting all types of barriers, and other after hitting the Armco/W-beam barrier specifically.

III. Data and Statistical Analysis

Fig. 2 demonstrates the data flow diagram with the number of case vehicles investigated through the various stages of analysis. The figure is self-explanatory. A total of 429 crashes (including 435 case vehicles) that resulted in severe and fatal injuries were selected for analysis. The crashes were thoroughly investigated during the period 2007-2012. Out of the investigated case vehicles, 169 vehicles were involved in rollover crashes. The data included 71 vehicles hitting barriers, out of which 46 vehicles were involved in rollover crashes. Moreover, out of these 71 vehicles hitting barriers, 46 vehicles hit the Armco/w-beam barrier type, out of which 30 vehicles were involved in rollover. The "sedan" category includes all the two-door (Hardtop coupe)/four-door sedan, convertible, sports, and hatchback (2/3-door or 4/5-door). The "LTV" category includes the station wagon (2/3-door or 4/5-door), panel van (2/3-door or 4/5-door), utility (2-door or 4-door), and off-road (4WD light/heavy duty). The "others" category includes the multi-purpose van, bus, and heavy truck.

Descriptive statistical analysis was performed and collated using SPSS [45] for the statistical analysis. Also, contingency tables were built to evaluate the association between the categorical variables. The Chi-square test of Independence and Goodness-of-Fit [46] was used to find out the association between categorical variables. The Odds Ratio (OR) [47] is applied for testing and quantifying the association between variables, and the confidence intervals for 95% confidence limits are reported for significant associations. The statistical significance was measured at the level α=0.05 and 0.1.

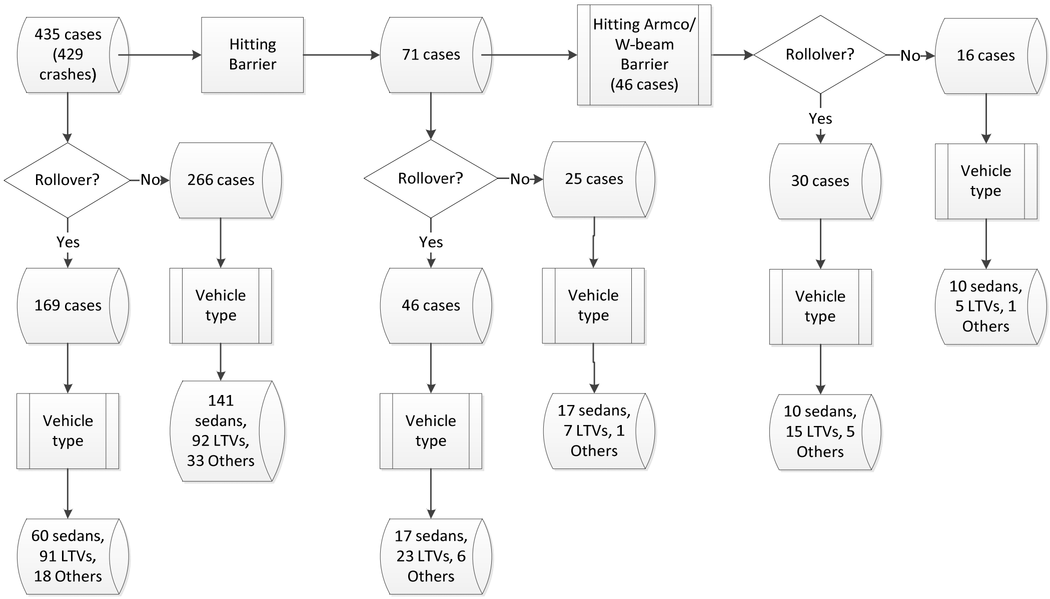

Fig. 2 Description of Analysis Data

TABLE I
DISTRIBUTION OF ROLLOVER INITIATION

Rollover Initiation	Frequency (%)
Before impact	16 (10%)
After impact	121 (71%)
No impact	27 (16%)
Between impacts	1 (1%)
Unknown	4 (2%)
Total	169 (100%)

IV. RESULT ANALYSIS

A protocol for analyzing rollover crashes was developed and applied to the data. This section, divided into three sub-sections, addresses in detail the relationship between rollover by vehicle types and also considering the rollover after hitting the barrier. First, the rollover crash features are summarized. Second, the features of rollover crashes after hitting barrier are presented. Finally, the features of rollover crashes after hitting the Armco/W-beam barrier are detailed.

A. Rollover Crashes Characteristics

This section addresses the features of rollover crashes in the context of rollover initiation types, location of rollover initiation, and the association of rollover crashes by vehicle type.

1. Rollover Initiation

The analysis of the 169 cases involving rollovers indicated that the majority of these rollover crashes occurred after impact (71% of the cases) as shown in Table I. Some rollover crashes occurred without impact (16%), and before impact (10%). Fig. 3 presents the distribution of rollover initiation types. The “Trip” and “Turn” categories are associated with the greatest proportion of rollover crashes initiations, summing up to nearly 50% of all rollover initiations. This percentage is quite close to the numbers reported by the Australian National Coroners Information System (NCIS) study [29].

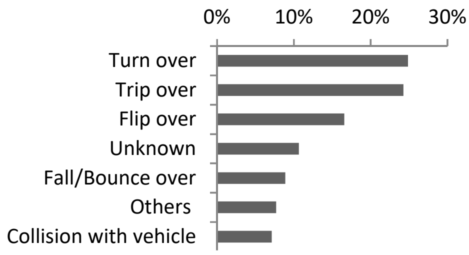

Fig. 3 Rollover initiation type

2. Rollover Location

The result of location where rollover initiated is presented in Table II. It shows that 39% of rollover crashes occurred on roadside and 29% occurred on roadway.

TABLE II
LOCATION OF ROLLOVER INITIATION

Location of Rollover Initiation	Frequency (%)
On roadway	49 (29%)
On shoulder - paved	17 (10%)
On shoulder - unpaved	23 (14%)
On roadside	66 (39%)
Rollover: end-over-end	5 (3%)
Unknown	9 (5%)
Total	169 (100%)

3. Rollover Crashes by Vehicle Type

In the study, 169 vehicles were subjected to rollover among which 91 vehicles were LTV and 60 vehicles were sedan. Table III shows the distribution of vehicle types with rollover status after hitting the roadside barrier. LTVS vehicles (54%)

were more likely to rollover than the sedan vehicles (35%) and this difference is highly significant ($\chi^2_{(2,N=435)}$ =16.236, p<.001).

TABLE III
DISTRIBUTION OF ROLLOVER STATUS BY VEHICLE TYPE*

Vehicle Type	Rollover		Total
	No	Yes	
Sedan	141 (70%) 53%	60 (30%) 35%	201 (100%) 46%
LTV	92 (50%) 35%	91 (50%) 54%	183 (100%) 42%
Other	33 (65%) 12%	18 (35%) 11%	51 (100%) 12%
Total	266 (61%) 100%	169 (39%) 100%	435 (100%) 100%

* Data in bracket represents row percentage

B. Rollover Crashes after Hitting Barrier

This section addresses the features of rollover crashes after hitting barrier, in context of rollover crashes rate for hitting barrier and the association of rollover crashes by vehicle type (sedan vs. LTV).

1. Rollover Crashes Rate for Hitting Barrier

A total of 71 vehicles were found in the database of hitting a barrier. Among these 71 cases, only 46 cases (65%) were rolled over after hitting the barrier. The other 25 cases (35%) did not rollover. The difference in proportions is significant ($\chi^2_{(1,N=71)}$=6.211, p=0.01).

2. Hitting Barrier and Rollover Crashes by Vehicle Type (Sedan vs. LTV)

Table IV shows the distribution of frequencies of vehicles hitting barriers, excluding the "other" vehicles. A total of 64 sedan and LTV vehicles were involved in hitting a barrier. The differences between the proportions shown in the table were found to be statistically significant ($\chi^2_{(1,N=64)}$=4.836, p=.03).

The odds value for LTV of being rollover is 3.29 (0.77/0.23) and for sedan is 1 (0.50/0.50). The odds ratio then becomes 3.29. For a 95% confidence interval, the odds ratio is (1.12 - 9.68, p=0.03). This suggests that the ratio of likelihood of rollover to not rollover for LTV is 3.29 times higher than the ratio of likelihood for the Sedan. This ratio may be higher considering the population data to reach 9.68, as estimated by the confidence interval of the odds ratio.

TABLE IV
DISTRIBUTION OF ROLLOVER STATUS BY VEHICLE TYPE*

Vehicle Type	Rollover		Total
	No	Yes	
Sedan	17 (50%) 71%	17 (50%) 43%	34 (100%) 53%
LTV	7 (23%) 29%	23 (77%) 58%	30 (100%) 47%
Total	24 (38%) 100%	40 (63%) 100%	64 (100%) 100%

* Data in bracket represents row percentage

V. CONCLUDING REMARKS

This research contributes to a better understanding of characteristics of rollover crashes in context of vehicle types as well as the rate of rollover after impact with barriers. The above results analysis can be utilized to provide some important insights on rollover crashes and its relationship with roadside barriers. First, it can be concluded that the majority of rollovers occur following some impact, and commonly on roadways as a result of initial force impacting the wheel/tyres. These conditions of rollovers are commonly encountered on the roadways when the vehicle hits a barrier. In such cases, the impact is commonly initiated on the wheels/tyres and results in turn/trip over (as concluded from the analysis).

The assessment of the assumption that barriers would likely affect the likelihood of rollover for some specific vehicle types, the 2nd stage of analysis was conducted. Studying the cases involving rollover following some barrier hit indicated a significant difference in proportions of the sedan versus the LTV vehicles. It also showed that the likelihood of rollover to not rollover of LTVs is more than three times higher than the likelihood in case of sedan vehicles. This odds ratio may reach more than 9 times for a confidence interval of 95%. It is apparent from these results that hitting a barrier will certainly increase the likelihood of rollover for LTVs as compared to sedans.

The type of barrier was further assessed in 3rd stage to conclude that the Armco/W-beam barrier does have a significant effect on rollovers. The likelihood of rollover to not rollover of LTVs is three times higher than the likelihood in case of sedan vehicles after hitting Armco/W-beam barrier. This odds ratio may reach more than 11 times for a confidence interval of 95%.

The above results suggest the necessity of revisiting the barrier design, heights and compatibility with the vehicle fleet. LTVs represent a significant portion of the vehicle fleet in UAE. The barrier standard heights should be revisited. This research is somehow limited in the sense that it did not account for the effect of the vehicle types with various barrier types. This is particularly due to the insufficient data to carry on such analysis.

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